Cloud Profiling Radar (CPR) for the CloudSat Mission

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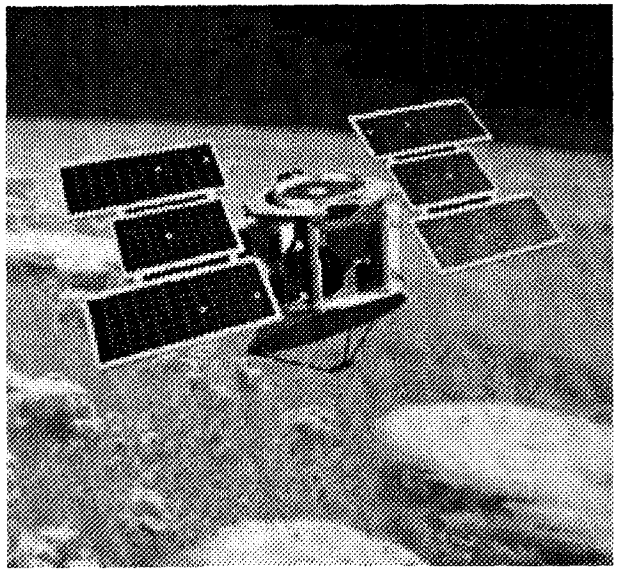
CloudSat Mission Overview

Key Features

- *Science payload:*
  - *94-GHz Cloud Profiling Radar (CPR)*
  - *Oxygen A-band Spectrometer/Imager*
- *BATC's RS-2000 spacecraft bus*
- *Co-manifested on Delta launch vehicle with the PICASSO-CENA spacecraft*
- *Flies in on-orbit formation with PICASSO-CENA and EOS-PM - 705 Km sun sync*
- *Launch date: March 2003*
- *Operational life: 2 years*



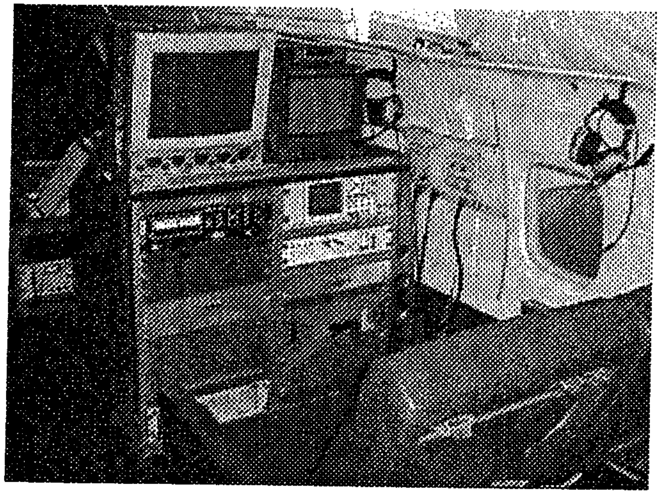
Science

- *Will measure vertical structure of clouds and quantify their ice and water content*
- *Will improve weather prediction and understanding of climatic processes*
- *Will improve cloud information from other satellite systems, in particular those of EOS-PM*
- *Will investigate the way aerosols affect clouds and precipitation*

Programatic:

- *CloudSat is the 4th NASA Earth System Science Pathfinder (ESSP) mission*
- *Cost capped at ~$111M (includes L/V)*
  - *Design to cost*
- *Mandated 3-year pre-launch development*
  - *Design to schedule*

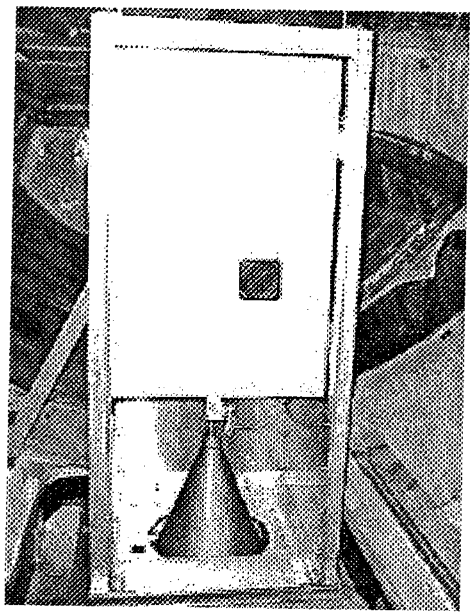
NASA/JPL/UMASS AIRBORNE CLOUD RADAR (ACR)



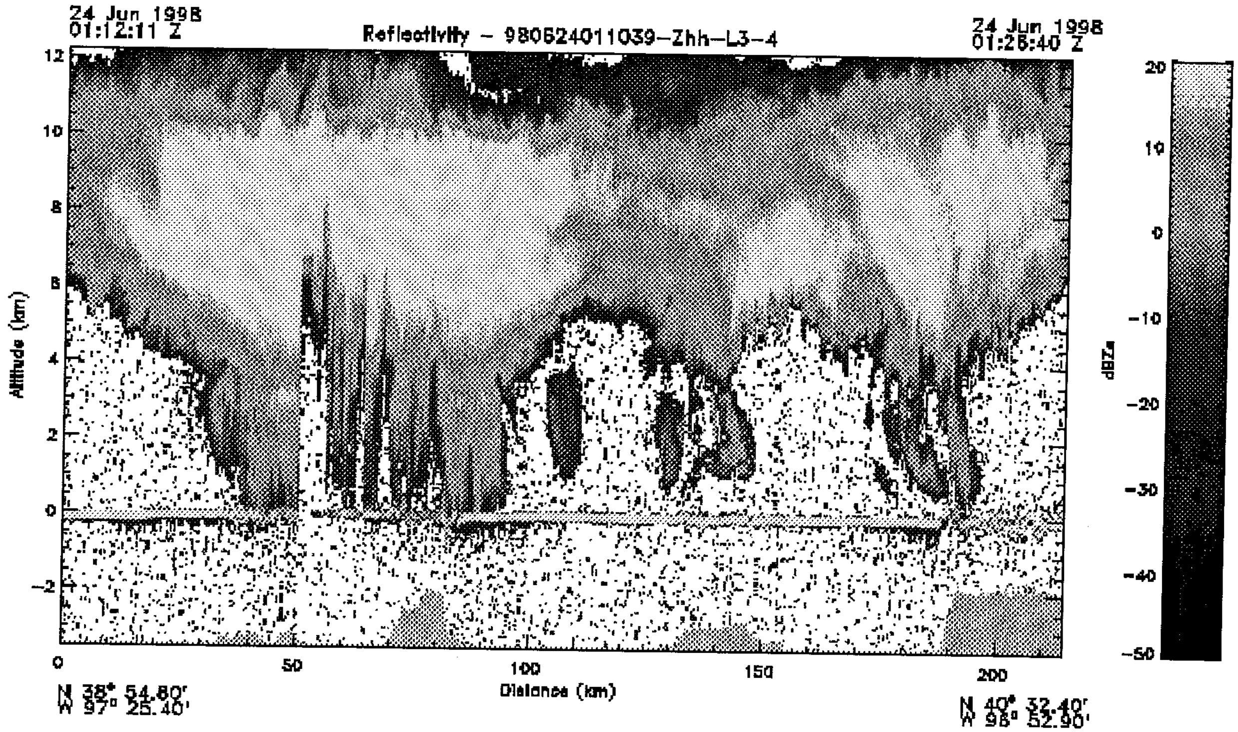
DC–8 95 GHz radar operator station

- AT LEFT ARE PHOTOS OF ACR OPERATOR'S CONSOLE AND RF ELECTRONICS AND ANTENNA INSTALLATION IN NASA DC–8
- BELOW IS A NADIR IMAGE OF CLOUD AND PRECIPITATION REFLECTIVITY ACQUIRED NEAR SEVERE THUNDERSTORMS IN NORTHEASTERN KANSAS ON 24 JUNE 1998

(HORIZONTAL AXIS IS ALONG–TRACK DISTANCE, VERTICAL AXIS IS ALTITUDE)

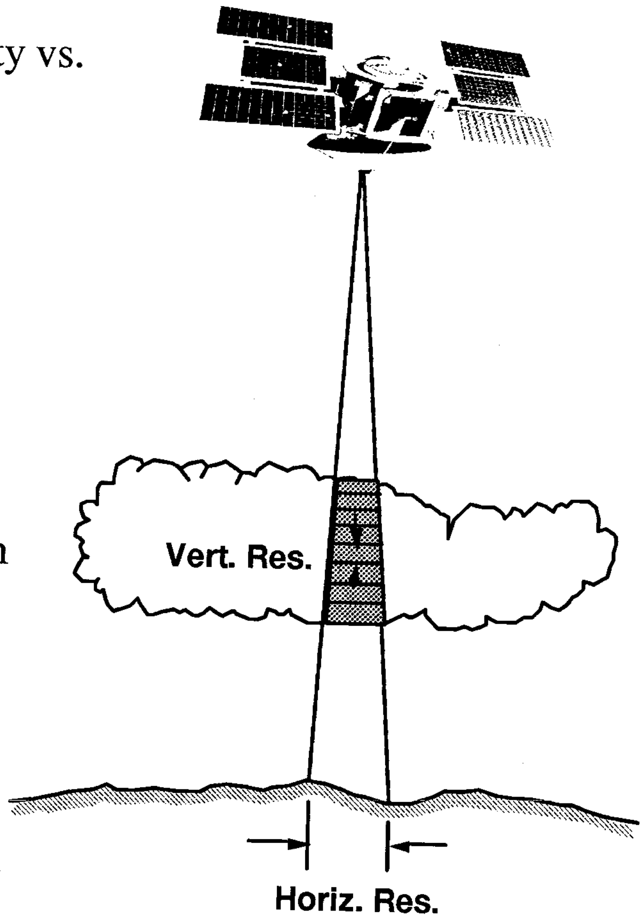


Nadir radar installation in aft cargo hold.



CPR Overview

- Nadir-pointing 94-GHz radar to measure cloud reflectivity vs. altitude
- Transmit 3.3-μs monochromatic pulses
  - Vertical resolution ~500 m
- Use 1.85-m dia. antenna for transmission/reception
  - Horizontal resolution ~1.4 km
- Nominal sensitivity: -28 dBZ
- Dynamic range:
  - Capture both low reflectivity clouds and ocean return
  - 0-25 km data window
- Physical characteristics:
  - Mass: 195 kg
  - Power: 234 W
  - Data rate: 25 kbits/sec



System Parameters

Parameter	Value
Nominal frequency	94.05 GHz
Antenna:	
Aperture diameter	1.85 m
Peak Gain	63 dBi
Beamwidth (3-dB)	0.12°
Sidelobes:	
<7° from boresight	-20 dB
>7° from boresight	-50 dB
Peak power	1500 W
Dynamic range	70 dB
PRF	4300 Hz
Pulse width	3.3μ s
Minimum reflectivity	-28 dBZ
Integration time	0.32 sec
Vertical resolution	500 m
Cross-track resolution	1.4 km
Along-track resolution	3.6 km
Along-track sampling	1 km
Vertical sampling	250 m
Science Data window	0-25 km
Data rate	25 kbps

Key Science and Mission Requirements Related to CPR

- CPR electrical boresight misalignment error < 0.0540°.
- Vertical resolution of CloudSat measurements shall be < 550 m.
- Measurements from surface to 25 km above the mean geoid.
- Detect reflectivities down to -26 dBZ at end-of-life.
- Calibration accuracy of 1.5 dBZ.
- The instantaneous radar footprint < 2 km.
- After along-track averaging, footprint < 5 km along-track and < 2 km crosstrack.
- Oversampling by at least 2x in the alongtrack direction.
- No systematic, geographically correlated gaps in the CPR data.
- Boresight at geodetic nadir to within 0.0678°.
- CPR placed in standby or off mode of operation during maneuvers.
- Orbit average data rate for the CPR < 25 kbps.
- Mass < 235 kg.
- Orbit average power consumption < 322 watts .
- Lifetime of 24 months.
- CPR electrical boresight misalignment error < 0.0540°.

Design Considerations

- Clouds are very weak scatterers; detection of low reflectivity clouds requires
  - –high peak transmit power
  - –large antenna
  - –large pulse width
  - –low front end losses
  - –low noise amplifier in receiver
  - –receiver bandwidth matched to transmit pulse
  - –estimation and subtraction of system thermal noise
- Besides thermal noise, clutter due to surface return must also be considered
  - –surface clutter results from previous pulses returning from surface simultaneous with return from clouds
  - –low antenna sidelobes are required
- Additional considerations
  - –pulse compression cannot be used due to sidelobe contamination from surface
  - –pulse width is limited by required range resolution
  - –along-track averaging is limited by required along-track resolution
  - –receiver bandwidth must accommodate STALO stability and Doppler shifts
  - –maximum signal from surface is 80-90 dB above minimum detectable cloud return

Receiver Simulation Studies

Method

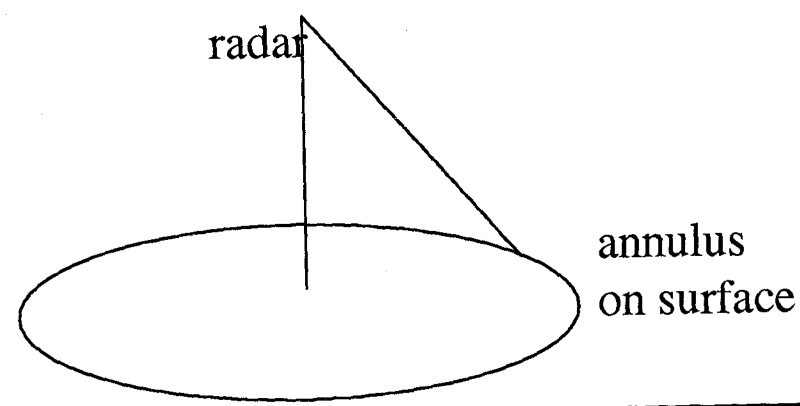
– generates detected signal from log amplifier using appropriate statistics
– simulates analog to digital conversion
– converts to linear domain
– averages
– codes for storage
– computes statistics of estimated power (signal+noise) and noise floor

Results

– maximum average signal should be several dB (4-6) below the maximum ADC input
– linear detection requires > 14 bits ADC; not available for space use
– log detection requires > 8-bits; use lod-detector with 12 bit ADC to get 10.5 effective bits
– antilog look-up-table should produce a power with > 20 bit representation; 24 are used
– accumulated powers must have proper representation to avoid bias; 32 bits integer or floating with 10 bits mantissa and 5 bits exponent seems sufficient; a (6,14) floating format provides a lower data rate than 32-bit integer and is chosen.
– log-detector must be linear for inputs that are at least 6 dB below the mean noise level at the log-detector input; 10 dB is preferred.
– system induced variations in the received power (due to transmit power variation or receiver gain variation must be < 0.5 dB over the integration time of 0.32 s)

Effect of Surface Clutter

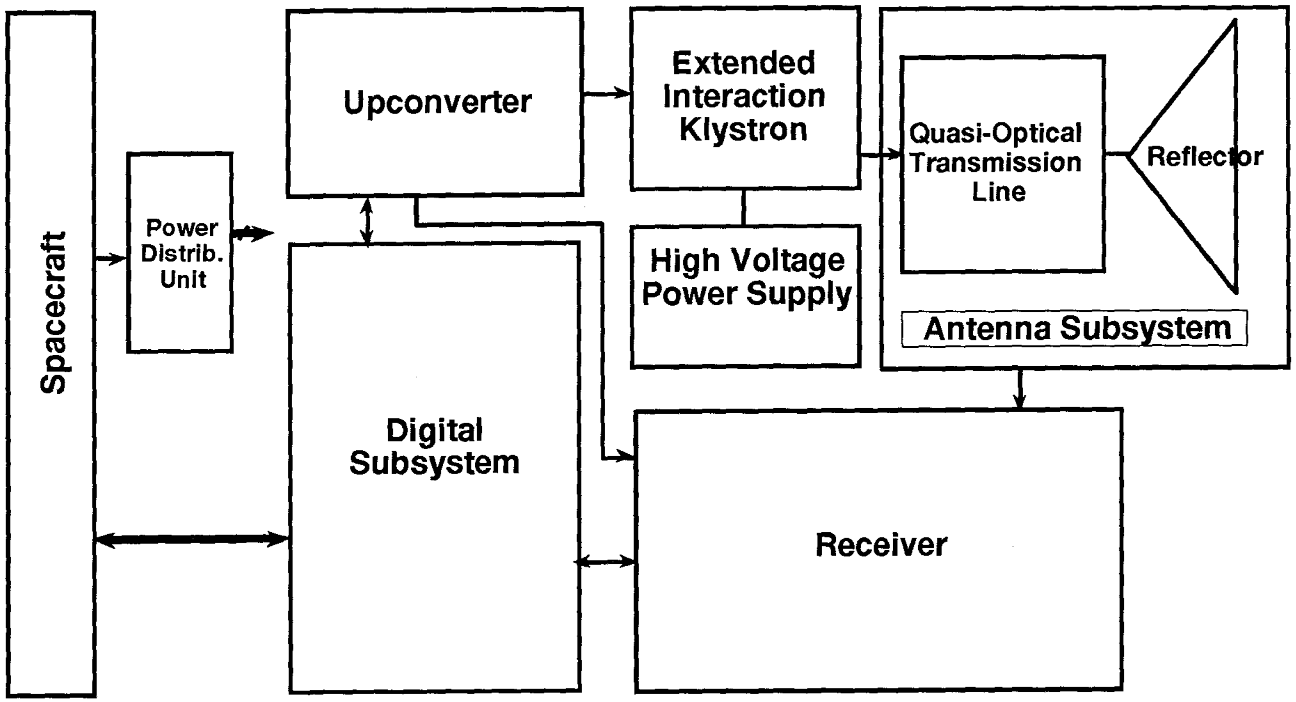
- For a nadir-looking radar clutter is due to return of previous pulses from surface (ambiguities) simultaneous with cloud signal.
  - signals from ranges r+nc/2PRF arrive simultaneously
- A mathematical analysis and computer software were developed to compute radar signal-to-clutter ratio versus cloud altitude
- Simplest design (single transmit frequency) has problems with clutter for worst-case antenna pattern (-38 dB sidelobes).
- Frequency diversity can be used to reduce clutter:
  - transmitter transmits a sequence of up to 16 separate frequencies, separated by 2 MHz
  - receiver is designed to track transmit frequency with appropriate delay for spacecraft altitude; return from 1st 15 previous pulses are now outside receiver bandwidth
- Using frequency diversity, an antenna with -38 dB sidelobes 7 degrees from boresight and beyond meets requirements.
- Current antenna provides -50 dB sidelobes
  - frequency diversity not needed



Calibration

- Internal approach
  - monitor transmit power using by coupling power from antenna subsystem to a detector diode
  - monitor receiver gain by periodically injecting noise diode into receiver front end
  - requires pre-launch measurements of antenna gain and front-end losses
  - accuracy depends on these measurements and their stability and noise diode and power detector accuracies
- External calibration using ocean surface measurements is also planned:
  - approximately once per month spacecraft will maneuver to point CPR antenna at 10 degrees in cross-track direction
  - CPR will acquire ocean sigma0 data during 10 minute data take
  - spacecraft will move antenna back to nadir
  - CPR will resume nominal science data collection
  - calibration data take will occur at night over ocean to minimize thermal effects
- The 10 degree angle is approximate and is based on observations at Ku-band
  - at Ku-band ocean sigma0 shows minimum sensitivity to wind speed
  - same physics should hold at W-band; however, angle of minimum sensitivity may differ somewhat
  - aircraft measurements could improve knowledge of ocean sigma0 prior to launch

CPR Block Diagram

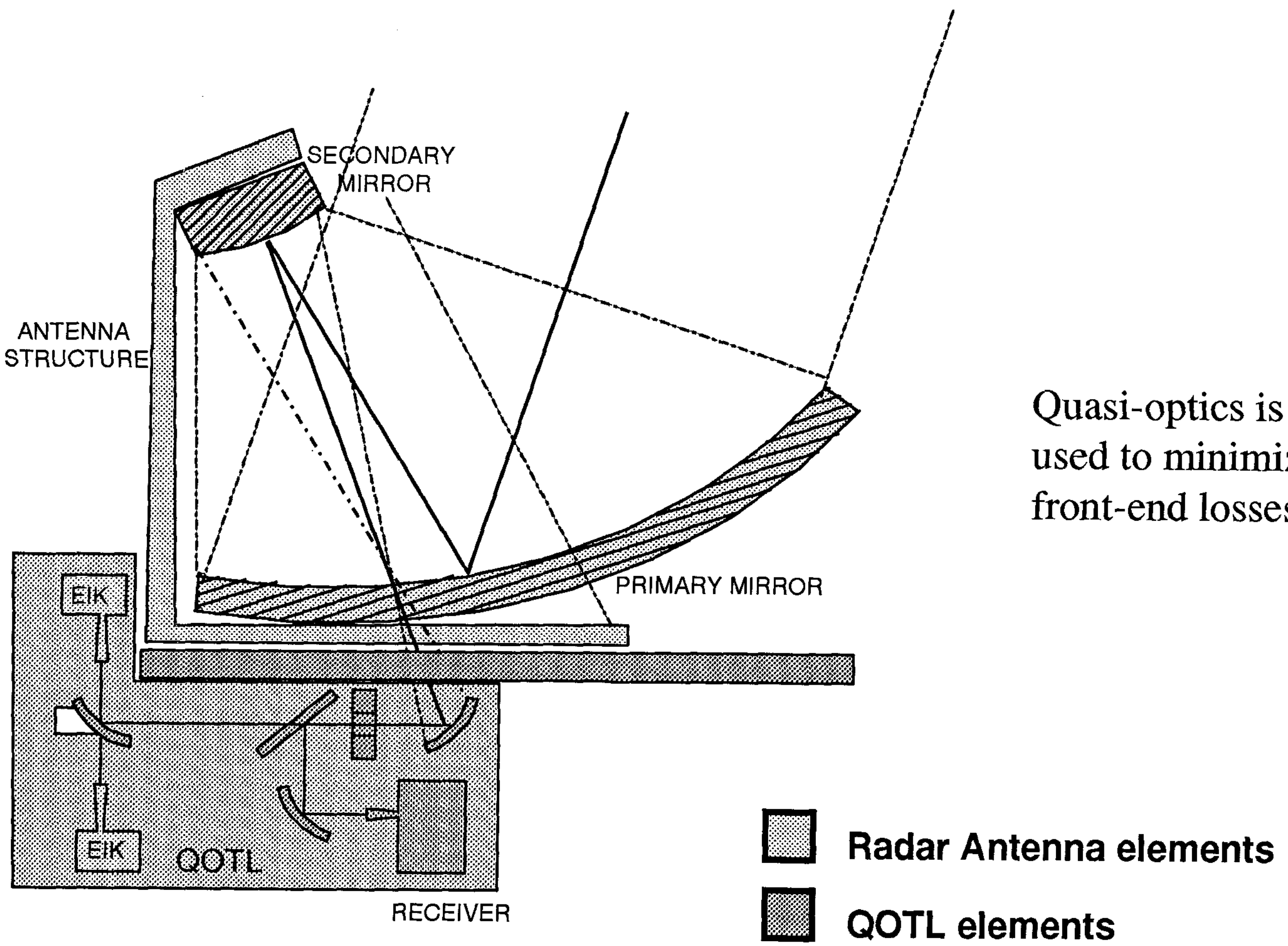


- <u>Upconverter</u>: convert lower frequency pulse to 94 GHz pulse
- <u>High Power Amplifier (EIK+HVPS):</u> Klyston tube amplifier which amplifies transmit pulse to ~1500 W
- <u>Antenna Subsystem</u>: ~2 m reflector and quasi-optical system (QOTL) for coupling transmit signal to antenna and received signal to receiver
- <u>Receiver</u>: amplify, downconvert, and log-detect received signal
- <u>Digital Subsystem</u>: generate transmit signal, provide control signals to other radar subsystems, interface with spacecraft, log-detect and digitize and sum data

Implementation Details

- CPR has only one science mode, short pulse data acquisition:
  - simple functional design allows control without microprocessor
  - FPGAs are used to implement radar control and processing functions
- RFES uses:
  - MMIC driver amps to generate medium power signal to drive EIKs
  - MMIC low-noise amplifier to minimize receiver noise figure
- A redundant high power amplifier is provided due to the EIK cathode's finite life.
- A quasi-optical transmission line (QOTL) implements duplexing function; reduces loss relative to conventional waveguide and circulator.
- Antenna is 1.85 m offset design, designed for high gain and low far sidelobes; peak sidelobes are not critical.

Antenna/QOTL Overview



Quasi-optics is used to minimize front-end losses

Conclusions and Summary

- CPR on the CloudSat mission will be the first spaceborne radar for cloud profiling.
- It will measure cloud reflectivity versus altitude using a conventional short pulse, providing 500 m range resolution and -28 dBZ sensitivity.
- CPR system requirements are in place and have been reviewed.
- While the operation of CPR is simple (1 science collection mode), the development of CPR has a number of technology challenges
  - space-qualified high power source (tube and power supply)
  - large antenna and quasi-optical feed
  - W-band medium power and low-noise amplifiers
- Design of the CPR subsystems is proceeding according to schedule for launch in 2003.